ADD #1

IRE Transactions

ON MILITARY ELECTRONICS

Volume MIL-1 **DECEMBER, 1957** **Number 2**

TABLE OF CONTENTS

PUBLISHED BY THE

PROFESSIONAL GROUP ON MILITARY ELECTRONICS

IRE TRANSACTIONS® ON MILITARY ELECTRONICS

Published by the Institute of Radio Engineers, Inc., for the Professional Group on Military Electronics at 1 East 79th Street, New York 21, New York. Responsibility for the contents rests upon the authors, and not upon the IRE, the Group, or its members. Individual copies available for sale to IRE-PGMIL members at $0.55, to IRE members at $0.85; and to nonmembers at $1.65.

Announcement of M. Barry Carlton Award

An Award to be known as the M. Barry Carlton Award for the best paper published in the PGMIL Transactions has been approved by IRE headquarters. An Awards Committee has been authorized by a change in the By-Laws and will judge the Award.

This Award will be a memorial to the late M. Barry Carlton, a member of the first administrative committee of the group. The award will consist of a certificate and a cash prize of $250.00.

It is fitting that this Award should be a memorial to M. Barry Carlton as he dedicated his life and finally gave it in promoting the reliability of communications equipment, particularly that carried in aircraft. It is ironic that he died on June 30, 1956 in the greatest commercial air disaster in history to that date. In this disaster, two airplanes crashed in the Grand Canyon in northern Arizona, apparently in a midair collision, killing all 128 persons aboard. While the cause of this crash has never been officially announced, it could well have been due to the failure of communications equipment aboard one of the two aircraft. Largely as a result of this crash, legislation establishing the Air Ways Modernization Board was passed by Congress, with a view to preventing crashes of this kind in the future.

M. Barry Carlton was a member of the Research and Development Board and later was Assistant Secretary, Research and Development in the Department of Defense. At the time of his death, he was employed by the Magnavox Company.

The rules governing the presentation of this Award are given below.

RULES

Purpose of the Competition

To promote greater interchange of information and publication of original and readable papers on the subject of Military Electronics published in the IRE-PGMIL Transactions each year.

Eligibility

1) Members of the IRE-PGMIL or Affiliates of PGMIL who are members of IRE.
   Authors or joint-authors of papers in PGMIL Transactions.
2) Papers must have been published initially in the PGMIL Transactions during the period of July 1 through June 30 immediately preceding presentation of the Award.
3) Eligibility shall be established by the individual's status at the time of recommendation to the Awards Committee.

Subjects

To be eligible for competition, papers must deal with subjects directly related to problems of Military Electronics falling within the general scope of activities of the Institute of Radio Engineers. Such papers should present to the readers information on new techniques, unique solutions to specific problems having general application to the profession, novel procedures and systems, and other pertinent topics of professional military electronics interest.

Judging

1) Final judging of the best papers will be made by the PGMIL Awards Committee from the papers published during the previous competition year period.
2) Recommendations for the award will be made to the PGMIL Awards Committee Chairman by the PGMIL Administrative Committee, PGMIL Chapter Chairmen, PGMIL members through their PGMIL Chapter Chairman, and by the Chairman of the PGMIL Papers and Publications Committee. Recommendations shall be accompanied by a statement of the reasons supporting the recommendation.
3) Judging of the papers will have been completed in time for announcement and presentation of the Award at the time of the first annual national convention of the Institute following the close of the eligibility year of the competition.

Awards

1) The Awards will be made on the basis of readability, originality, and the general quality of the papers, including such items as subject matter, timeliness of the subject matter, and the contribution to the field of military electronics. The Award will consist of a certificate and a cash prize of $250.00. In the case of joint authorship, certificates shall be given to each author and the cash award divided between them in equal parts.
2) Decisions of the Awards Committee shall be final in judging of papers. The award shall be omitted for lack of a qualified recipient or for inability to comply with any of the requirements set forth.
3) No member of the Awards Committee nor any Administrative Committee member is eligible for an award during his tenure of office.

Presentation of the Award

The Award shall be presented with appropriate ceremony at the Annual Banquet associated with the Annual National Meeting of the Professional Group for Military Electronics next held after the expiration of 90 days from the conclusion of the awards period.

Editorial

With the institution of the M. Barry Carlton award for the best paper of the year, a real personal incentive has been established to generate interesting and informative papers for publication in the PGMIL Transactions. This marks another step taken in the long-range program to develop a professional journal of unique significance in the field of military electronics. The objective of the program is to stimulate new lines of thought. By cross-breeding the various scientific disciplines, even old ideas can take on new importance. By presenting the fundamental concepts underlying the present state of the various electronic arts, and perhaps speculating upon some of their logical extensions, new concepts may evolve that could lead ultimately to truly important discoveries.

To achieve this objective, it is essential that the ideas presented be clear and understandable to workers in widely different areas of military electronics. They should be interesting and stimulating, appealing to the imagination as well as to the intellect. By re-examining the basis for the present state of scientific knowledge, it well may be that a fresh approach to some of the existing unsolved problems could result in real advances in the state of that knowledge. Never before in the history of scientific achievement has the need for new knowledge been greater than now, the dawn of an era of space exploration and possibly the beginning of an international struggle for astronautical supremacy. Therefore, we submit to you, the membership, this plea: Re-examine the fundamentals of your respective fields, summarizing the present state of the art and its possibilities for the future as you see it, and present your work for publication in the PGMIL Transactions.

—*The Editors*

A Message from the National Chairman

Several things have happened to PGMIL since we last went to press and they are all most encouraging.

First, we had a test of strength with a national meeting in June in Washington, D.C., and came out very well indeed! Dick Frazier put together an excellent technical program on "Missiles and Electronics" of more than 100 papers. All sessions were in the hands of fine moderators. One classified session found itself in a broiling auditorium, but even there the attendees were numerous and attentive. John Klotz and his staff and Dave Whitelock ran local arrangements and exhibits like the "old Pro's" that they are, so we registered 1584 at the door and came out with a very respectable cash balance for the use of the Group. Lt. Gen. C. S. Irvine, USAF, was our principal speaker. He is dedicated to the task of getting truly reliable electronic equipment into service. He spoke from a background so extensive in military material that it was, in itself, awesome, and his talk was an inspiration.

Next, our number of chapters has risen to fifteen, up 50 per cent in six months.

We are jointly sponsoring a National Symposium on "Human Factors in Systems Engineering" at Philadelphia, Pa., in December. We have responsibility for two sessions at the National Convention in March in New York, N.Y., and we are going ahead with plans for our 1958 National meeting in Washington, D.C., in June. Brig. Gen. Walter LaRue, USA (Retired), now with Melpar, will be the Convention Chairman, Bob Cranshaw will handle local arrangements, and Dave Whitelock, the exhibits. The theme tentatively is "Missiles and Electronics—1958."

On July 1, I was honored with the National Chairmanship of PGMIL. I am particularly anxious to see that our group includes a good proportion of engineers in military service, in and out of uniform, as well as those in industry who are engaged in military work. The tempo of recent events points out very clearly the vital roles and the fast increasing responsibility of our engineers. There certainly is a place for PGMIL in this terrific job which faces us.

—*W. E. Cleaves*

Instrument Landing at Sea*

F. AKERS† AND F. G. KEAR‡

Summary—The paper is a narrative account of two years of intensive effort by the Navy and civilian engineers which, after many trying periods, achieved success on July 30, 1935, when a completely hooded instrument landing was made aboard the aircraft carrier, *USS Langley*, 100 miles at sea off San Diego, Calif.

In the summer of 1933, when the aircraft carrier emerged as the future striking power of our Navy, Rear Admiral Ernest King, Chief of the Bureau of Aeronautics (later Fleet Admiral King), was hunting for every means to improve the capability of our carriers. One of the most important was their ability to operate in all types of weather. As a result of his examination of the Bureau of Standards' development work on an instrument landing system, he negotiated a contract with the Washington Institute of Technology to apply the basic principles and modify this system for aircraft carrier operations. The Washington Institute of Technology was formed specifically for the purpose of developing this system under the presidency of Sidney Mashbir. The development engineers were Gomer Davies and Dr. Frank G. Kear. Lieutenant Frank Akers, U. S. Navy (now Rear Admiral), was designated the project officer and flight test pilot for this effort. The small field at College Park, Md., was chosen as the location for the tests.

Throughout the fall and winter of 1933 and 1934, the equipment was built and many test flights made. A satisfactory installation was completed so that by May, 1934, completely hooded instrument landings were being made regularly at the College Park Airport.

Satisfied with the success of the ground installation, Admiral King decided to have the equipment installed aboard our first aircraft carrier, the *USS Langley*. The structural work was done at the Norfolk Naval Shipyard at Portsmouth, Va. The *Langley* sailed back with the fleet to the Pacific Ocean. The equipment installation was completed by the fall of 1934 and flight tests began. Many unexpected problems were encountered particularly in regard to the glide path and localizer. These resulted in some rather major modifications, but eventually they were solved and an entirely satisfactory system was completed which resulted in the successful landing at sea by Lt. Akers on July 30, 1935.

Introduction

During the period 1928-1932, the aircraft industry was seriously concerned with the problems of instrument flight. In these few years, the relatively crude instrumentation used by the air mail pilots had been improved to the point where the artificial horizon and directional gyro were worthy of confidence under instrument conditions. At the same time, the radio aids kept pace. The visual-range beacon was being accepted and automatic direction finders had made an appearance. While all of this development was underway, the Bureau of Standards at its College Park, Md., laboratories was working on a system which would permit landing an aircraft under conditions of low or zero visibility. The system which they developed possessed, in crude form, the same features associated with the universally used instrument-landing systems of today. A localizer beacon defined the position of the runway to be used in landing. Marker beacons along the localizer path marked the progress of the aircraft along its approach. Finally, the glide path provided an indication which, if followed, could keep the aircraft clear of obstruction during the descent and insure safe contact with the ground along the runway.

In the spring of 1933, an instrument-landing system incorporating these features was installed at Newark Airport. After thorough tests were made of the various elements of the system, Department of Commerce personnel not only made complete instrument landings at Newark but also completed at least one flight from Washington to the landing field at Newark under instrument conditions.[1]

During this same period, the United States Navy's carrier force began to emerge as the striking power for the fleet. The *USS Ranger* was about to join the fleet and three more carriers had been authorized. The fullest use of these carriers required the aircraft to operate therefrom without dependency upon weather conditions, if this was possible. In seeking to achieve this, the Chief of the Bureau of Aeronautics, Rear Admiral Ernest J. King (later Fleet Admiral) inspected the College Park installation of the Bureau of Standards and decided that it should be tried for carrier landings. Accordingly, a contract was negotiated to modify the Bureau of Standards' design to the extent necessary to permit its use aboard an aircraft carrier and to carry out the necessary flight tests. It was decided that the original modification should be land based and if the results were satisfactory, the equipment would be moved to an aircraft carrier for service tests. Lt. Frank Akers (now Rear Admiral) was designated as project officer for the operation.

Development Work at College Park

Planning started immediately and the first steps included the selection of an appropriate flying field and an

* Manuscript received by the PGMIL, September 23, 1957. The opinions or assertions contained herein are the private ones of the writers and are not to be construed as official or reflecting the views of the Navy Department or the naval service at large.

† Rear Admiral, U. S. Navy, U. S. Naval Air Station, Memphis 15, Tenn.

‡ Capt., USNR, Kear and Kennedy, Consulting Engineers, Washington 6, D.C.

[1] For a technical description of the basic elements of the instrument landing system, tests on which are described in this article, the reader is referred to the following publications:

H. Diamond and F. W. Dunmore, "A radio beacon and receiving system for the blind landing of aircraft," Proc. IRE, vol. 19, pp. 585-626; April, 1931.

H. Diamond, "Performance tests of a radio system of landing aids," *Natl. Bur. Stds. J. of Res.*, vol. 11; 1933. (RP602.)

W. E. Jackson, "Status of instrument landing systems," Proc. IRE, vol. 26, pp. 681-699; June, 1938.

aircraft with which to test the equipment. The field at the Naval Air Station, Anacostia, was too congested for this type of work and after a rather thorough survey, the field at College Park, Md., next door to the University of Maryland, was selected. On this field was located a private flying school which comprised practically all of the traffic out of it. All runways, of course, were unpaved and it was quite small by present-day standards, the longest runway being about 2200 feet. A contract was negotiated for use of this field by the Navy and property was obtained at the end of the runway for the erection of a structure to house the transmitting equipment, the development laboratory, and office space. All of this was done very quickly and in a matter of weeks the structure began to arise (Fig. 1 below.)

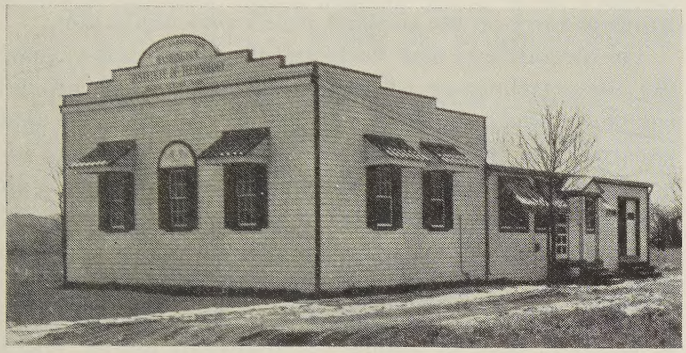


Fig. 1—Building housing transmitting equipment for instrument landing tests, College Park Airport, College Park, Md., 1933.

At the same time, a selection of the test airplane was made, a Berliner Joyce—Navy OJ-2 which was a standard observation plane for the Navy. For a number of reasons, it was decided to use the rear seat for the test pilot leaving the front seat available for a safety pilot. Brakes had to be installed for the rear seat along with various other minor structural changes, and a complete instrument panel was provided.

A considerable amount of planning went into the makeup of the instrument panel. Gyro-type instruments were just coming into the Navy and only the newer type aircraft were being fitted with directional gyro and artificial horizons. These were essential if instrument flight was to be conducted, and a number of mockups of instrument panels were tried out in order to obtain the proper grouping for ease of reading for instrument flying.

The only special visual instrument was the "cross pointer" which had been developed during earlier work at the Bureau of Standards and by the Bureau of Air Commerce. In its original form and as used in this project, the instrument was so connected that the intersection of the two needles represented the aircraft and the small circle in the center of the instrument face represented the path. In following the instrument indications, the pilot endeavored to fly this intersection toward the circle.

Another radio aid included in the aircraft was an automatic direction finder. While not in the refined form of the type used today, it provided the pilot homing information by means of a right-left indicator. With the aircraft headed toward the station to which the direction finder was tuned, the needle of the indicator would be centered. Deviation from the correct heading would indicate directly to the right or the left, thus giving the pilot homing information. In this installation a switch under the control of the pilot conveyed this homing information to the vertical needle of the cross pointer instrument.

Upon completion of the structural changes and the installation of the instrument panel in the OJ-2 airplane, instrument-flight training was begun by Lt. Akers in order to perfect his skill in this type of flying. One must remember that during this period, instrument card qualifications with set training procedures therefor were not in effect in the Navy. This meant that Lt. Akers must develop his own procedures for flying on instruments from his own analysis and by trial and error procedures. Many hours were spent under the hood (with a safety pilot in the front seat) flying on the radio ranges throughout the East Atlantic states and perfecting a satisfactory technique. This training went on while the ground equipment at College Park was being designed and built.

Fig. 2 shows the airplane, with the glide path antenna on the leading edge of the upper wing.

Fig. 2—OJ-2 Airplane equipped for instrument landing. Glide-path antenna on forward edge of upper wing. *Left to right:* Lt. Frank Akers, USN, Project Officer; D. L. Gentry, Capt., USN, Check Pilot; Rear Admiral Ernest J. King, USN, Chief, Bureau of Aeronautics, College Park Airport, 1933.

While the project officer developed instrument-flight techniques, the engineers at College Park were busy with redesign and modification of the Bureau of Standards system to meet the new demands of carrier operations.

Adapting the equipment for eventual use on a carrier with standard Navy aircraft required modifications which were not all straightforward.

1) The localizer beacon or runway localizer of the Bureau of Standards operated on a frequency of approximately 300 kc and a pair of crossed-loop antennas produced the conventional figure of eight pattern. Now it became necessary to modify this equipment to operate on a frequency of approximately 12 mc and with a high order of frequency stability. This change in frequency was made to accommodate the frequency plan for carrier based aircraft. To suit both this frequency plan and carrier operations, the College Park localizer antenna consisted of three quarter-wave vertical radiators spaced 90°, and on a line. The 65-cycle and 86.7-cycle modulated carrier signals were delivered to these three antennas in such fashion as to produce intersecting cardioid patterns. This eliminated the loop antenna previously used and permitted establishing a single course from the localizer rather than the intersecting courses established by loop antennas. At the time, this was quite an innovation.
2) The glide path operated on a frequency of 92 mc and since it required special receiving equipment, no frequency change was necessary; however, it was necessary to reduce the transmitting-antenna system to a size which would permit its location on the flight deck. The path shape also required study. While operation at College Park permitted use of the same type of path that had been employed by the Bureau of Standards, it was kept in mind that transfer to a carrier would add still another problem. The glide path then in use was the curved type. The aircraft approach was made on a locus of constant field intensity which was substantially parabolic. If we assume a runway 2200 feet long and a point of touchdown 1000 feet from the glide path transmitter at the downwind end thereof, the shape of the path is determined then by the height of the glide path antenna above the ground at point of touchdown; for example, if the antenna was ten feet off the ground and touchdown 1000 feet from the antenna, then at 3000 feet, or three times the distance, the path would be 90 feet above the ground, and at two miles the aircraft would be at an altitude of approximately 1000 feet. It had been demonstrated already that a path of this shape could be used by aircraft and this type of path was used for the College Park tests.
3) Since it did not appear possible to locate several marker beacons along the approach path, the Navy tests were limited to the use of a single marker. This was located at the edge of the runway nearest to the pilot on approach and represented the stern of the carrier landing deck. The marker beacon produced an aural indication only and the signal was received on the same receiver which provided the range beacon information.

Another unique feature of the Navy development which facilitated tests and training was the use of two-way communication between ground and aircraft. At this writing, it seems difficult to believe that such communication was not customary; however, practically all of the Bureau of Standards' development was carried out with one-way communication only, from the ground to the aircraft, and this was none too certain.

By winter of 1933, the various transmitters and their associated equipment were completed and initial tests commenced. Radiation patterns were taken both from the air and by portable equipment in a truck. Many days followed in repetition of this strenuous procedure making adjustments and modifications both in the aircraft installation and in the equipment on the ground. Unfortunately, this was one of the rather bitter winters in Washington with much snow, and as there was no hangar in which to work on the airplane, it was very unpleasant.

The aircraft was now ready and the pilot had developed the basic techniques of instrument flight. The ground equipment was complete and producing the calculated field patterns. The two elements were ready to be brought together and this was the responsibility of the pilot. With practically no previous experience on which he could draw, or pilots skilled in instrument landing with whom he could confer, it was necessary to develop a proper procedure for landing under a hood and one that could be later employed in landing on an aircraft carrier. After lengthy experimentation with various procedures, the one described in the following paragraphs was adopted.

The principles of the system employed are basically the same as the present ILS and have been described in detail in many other papers.[1] From the pilot's point of view, they consisted essentially of a radio direction finder with a visual indicator, a cross pointer for final approach and landing, and an aural signal at the end of the runway for a marker. Once having located the field, he flew down the reverse landing course of the localizer (which was oriented on the landing runway) at about 1000 feet, using a time procedure. When he was downwind about five miles from the transmitter, he turned off to the right and then gradually turned all the way back left to the landing course. By watching the vertical needle of his cross pointer instrument, after a small amount of practice and even with varying crosswinds, he was able to come out of his turn upon the landing course pretty well lined up with the localizer beam. The glide path which controlled the horizontal needle of the cross pointer was at this time indicating full scale, or "too high." Thus, it was necessary for the pilot to gradually descend until he was on the proper glide path with the horizontal needle level. From that point in, it was a question of maintaining cross pointers in the bulls-eye and keeping his air speed about ten knots above stalling speed. This rather critical approach speed was necessitated by the short length of the runway at College Park, which was only about 2200 feet. As he approached the end of the run-

way, the marker beacon signal came into his earphones and rose in intensity until he passed the downwind end of the runway, then cut off sharply indicating to the pilot that if his cross pointers were in the bulls-eye, *and* if he was on the prescribed runway heading, *and* if his air speed was within the limits of not more than ten knots above stalling speed, it was safe to land. This was accomplished by a somewhat mechanical procedure of gradually closing the throttle (at this time with a correct approach the engine would be turning about 1100 rpm's) and slowly pulling back on the stick so that the airplane settled on in a three-point position. If the runway had been longer, a simpler procedure would have been that having once passed the end of the runway to make a power stalled landing and thus, take away the necessity of a more or less timed mechanical procedure. As can well be imagined, many tedious hours were required during these months of testing the equipment and the training of Lt. Akers.

In the fall of 1933, there occurred what might have been a most unfortunate accident. When Lt. Akers was taking off from College Park to return to the Naval Air Station, Anacostia, he was using the runway which had the transmitter house at the upwind end of it. Shortly after the plane was airborne and when about 15 feet in the air, the control stick in the rear seat came out of its socket and there was the pilot holding the stick with no airplane upon the end of it. There was no safety pilot in the front seat so all that could be done was to cut the switches and fortunately the airplane settled upon the ground in a level attitude but tail high and with far too much speed to be braked to a stop within the existing distance. At the end of the runway it became necessary to brake the airplane to a point where it went upon its nose and over on its back. Fortuately, only a small amount of damage was done to the plane and none to the installed equipment, and within a week the airplane was back flying, none the worse for wear.

On another occasion, a nearly serious accident took place in which the airplane settled too fast. When only a short distance downwind from the end of the runway the plane settled a little low and went through the top of a tree which was growing directly on the approach line and unfortunately had to be accepted as one of the hazards of these flight tests. However, no real damage resulted from this and a little dope and fabric quickly repaired the holes punched through the wings.

Finally, in the late spring of 1934, the equipment adjustments were determined definitely plus procedures to keep the indicators stable so that they would not vary from day to day with varying climatic conditions; likewise the pilot had progressed in efficiency of flying this system, so that complete "blind" landings were attempted with the pilot under a hood. Figs. 3 and 4 show the aircraft in final approach and at the moment of touchdown on one of these complete "blind" landings. From May 1 on, many of these landings were made. Demonstration flights were also made using various senior naval aviators as observers in the front seat during the landings. The procedure was to taxi out to the runway at the Naval Air Station at Anacostia, line up on the runway, then close the hood over Lt. Akers. From this point on, he took off blind, found the field at College Park by means of the visual direction finder, lined up on the localizer and glide path, landed on the field, and did not open the hood until the airplane had come to a complete stop. During all this period, particularly during the trying time when nothing seemed to work right, complete support and great moral help was always forthcoming from Rear Admiral King who was then Chief of the Bureau of Aeronautics and who had great confidence in successful completion of the project.

Fig. 3—OJ-2 Airplane in final approach. Pilot under hood, College Park, Md., May 1, 1934.

Fig. 4—OJ-2 Airplane at moment of touchdown. Pilot still under hood, College Park Airport, May 1, 1934.

Instrument Landing Goes to Sea

The repetition of successful instrument flights from take-off at Anacostia, under the hood, to final set-down at College Park encouraged the Navy Department to consider the installation and test of this equipment aboard ship and the old aircraft carrier, *USS Langley*, was chosen for this job. A new contract was negotiated and plans got underway for this undertaking. The *Langley* came east with the fleet and it was hoped first to bring her up the Potomac to the Gun Factory for the work. However, it was finally decided to do it at the Naval Shipyard at Norfolk, Va. Here again, a great effort ensued to meet a tight time schedule so that the *Langley* might sail back to the west coast with the fleet.

The flight deck of the *Langley* was 454 feet long, a mere

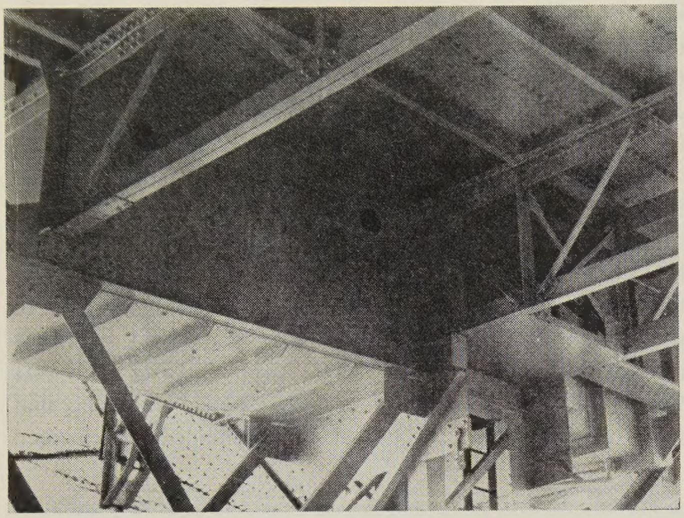


Fig. 5—Port forward portion of flight deck, *USS Langley,* showing transmitter and machinery rooms.

parking space compared to the flight deck of present day carriers such as the *USS Forrestal.* It was agreed that the aircraft making a landing must engage the second wire of the arresting gear if the landing was to be successful. Otherwise, the landing would be too close to the barrier with the possibility of damage to aircraft and personnel. The second wire was some 40 feet from the after edge of the flight deck. The marker signal could be given only as the plane passed the edge of the flight deck, so from the time the marker signal was given the pilot had 40 feet in which to engage the gear.

Another handicap arose from the speed of the *Langley.* Fourteen to eighteen knots of wind over the flight deck was about par. This relative wind velocity was of but little help in effecting the landing even when dealing with aircraft such as the OJ-2. (Landing speed about 65 mph.)

The *Langley* put into the Norfolk Navy Yard in the summer of 1934, and, while undergoing miscellaneous upkeep and repair, the equipment from College Park was moved to Norfolk and installed aboard. Steel plates were welded on the underside of the forward edge of the flight deck to form a room which would house the localizer transmitter, the glide path transmitter and the rotating machinery. (See Fig. 5.) It was far from commodious, but ample for the purpose intended. Instead of shock-mounting the equipment, the transmitter frames were welded to the deck which proved to be quite satisfactory.

At this point a change was made in the localizer design. It was found out that fleet frequency plans called for the use of 8 mc rather than 12 mc so it was necessary to reconstruct the localizer transmitter to cover this new frequency range.

The glide-path antenna was reduced to a single-driven element one wavelength long with a reflector a quarter wave behind. The antennas were mounted on a wooden frame work which in turn was supported by an elevator-type structure permitting the entire array to be raised and lowered. When lowered, it fell into recesses in the flight deck, thus presenting no obstruction to aircraft movement.

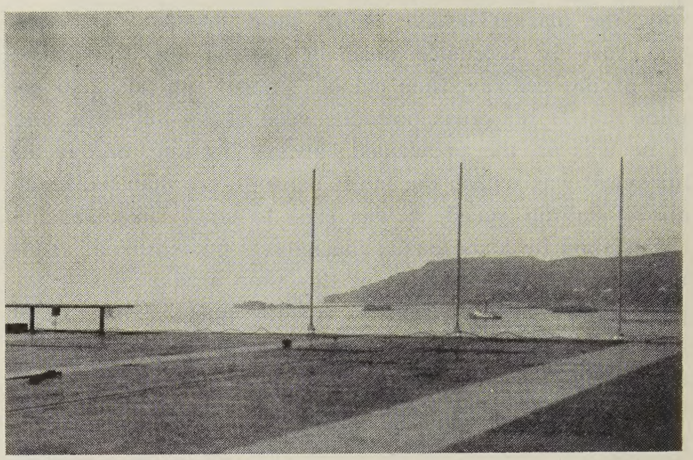


Fig. 6—Flight deck *USS Langley.* Landing-beam antenna on left; first form of localizer antenna on right.

The antenna appears on the left in Fig. 6.

The localizer antenna system on the *Langley* went through several stages. In the first configuration, three vertical quarter-wave radiators were installed on the forward edge of the flight deck. They were hinged and counter-balanced so that they could be folded rapidly. When folded, they were below the level of the flight deck, thereby creating no interference. These antennas can be seen at the right of Fig. 6.

The marker beacon and the two-way communication system were housed in a steel cage just forward of the after edge of the flight deck and underneath it. The marker beacon antenna was a long wire extending athwartship just aft of the after edge of the flight deck and below it. The communication antenna was mounted clear of the nets on the port side.

The installation of the items of equipment and the interconnection of the various parts of the system was completed in the fall of 1934, at which time the *USS Langley* joined the fleet which was then in the Atlantic and returned to its home port in San Diego where the flight tests commenced.

Problems Afloat

Needless to say, the installation presented numerous unexpected problems some of which, at times, threatened to make the system unworkable. Fortunately, it was possible to attack the problems one by one which greatly facilitated their solution.

The shape of the glide path was the first problem. With a flight deck 450 feet long and a point of touchdown 400 feet from the antenna, it was necessary to modify the aircraft installation in order to secure a satisfactory path. If the landing beam receiving antenna was retained at its former location at the leading edge of the upper wing of the aircraft, the effective path would be 10 feet high, 400 feet from the antenna. Since the path employed was essentially parabolic, this would mean at 4000 feet the path would be 1000 feet in the air requiring far too great a rate of descent. The antenna was relocated accordingly between the wheels of the aircraft landing gear as shown on the

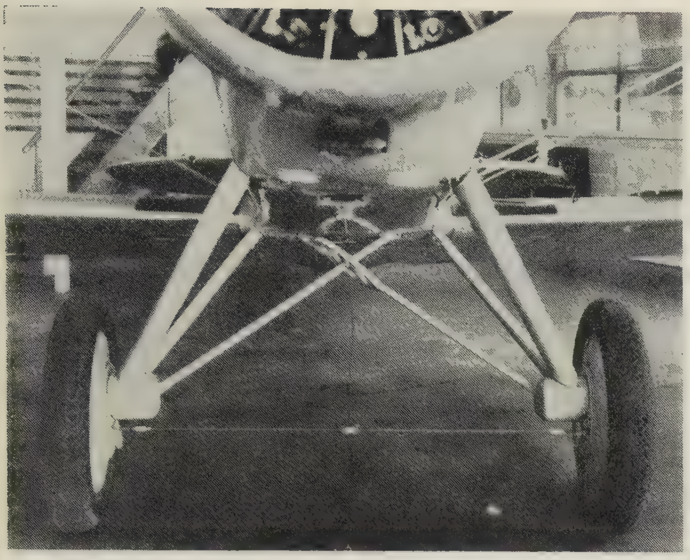


Fig. 7—OJ-2 Airplane showing glide-path antenna mounted between landing wheels.

photograph, Fig. 7. This resulted in a landing path one foot high at 400 feet or 100 feet high at 4000 feet, thus, permitting more nearly conventional landing practices. In order to utilize the signal at a point so close to the ground plane, that is to say, the flight deck, it was important that the power output of the landing beam transmitter be as great as possible. To achieve this, the transmitting-antenna system was designed to position the antennas eight feet above the flight deck when in operating position. This produced adequate power for the purpose intended but it also meant that the point of reflection of the transmitted signal shifted from the flight deck to the surface of the water some 50 feet below when the aircraft exceeded a certain distance from the carrier. This produced a bend of the landing path of such fashion that an approaching aircraft following the indications of the cross pointer instrument would descend almost to the water level when about two miles astern of the carrier and then would be required to climb to intercept the normal path as the carrier was approached, a rather hazardous maneuver. Fortunately, this was solved rather simply by lowering the antenna system to a point some two feet above the flight deck. This kept the point of reflection on the flight deck. The power available was still adequate to establish a proper flight path even at this height.

Naturally, it was very difficult to determine the exact nature of the path while the carrier was underway. However, it was found that with the carrier moored to the dock at North Island the glide path was directed to the south along the lower bay of San Diego. The location of numerous anchor buoys in the bay permitted accurate positioning of the aircraft with respect to distance from the carrier. Correlation of this distance information with altimeter readings permitted careful checks on the various glide path patterns and successive flight tests on these patterns resulted in establishing the glide path approach without the necessity for getting underway.

Fig. 8—Experimental localizer antenna on flight deck of *USS Langley*. Crossed loops produced localizer pattern. Central vertical antenna carries voice and provides homing information. Tuning elements on final model located beneath flight deck with loops and vertical antenna designed to plug in.

The localizer transmitter employing the vertically polarized array presented a more serious problem. Not only did reflections from objects on shore create interference to the radiated patterns but the location of the antennas on a relatively small conducting surface with sharp discontinuities therein resulted in severe shifts in polarization in consequence of which multiple courses were created and the localizer indication was useless for approach purposes. The antennas were relocated further down the flight deck but no substantial change was noted. It will be recalled that the *Langley* was a flush deck carrier with no island so that there were no obstructions above the flight deck to create trouble. For many days flight after flight was made with the *Langley* underway trying different configurations of antenna and different methods of tuning but without producing a field pattern which could be interpreted.

It was finally decided that the major source of error lay in the discontinuities of the ground plane. One solution might be to return to a type of antenna whose pattern was relatively independent of the ground plane, that is to say, a loop antenna. Accordingly, loop antennas were built and a temporary installation placed upon the flight deck. The results were very gratifying. While the field pattern was not free from minor irregularities, the loop antennas did establish a true localizer course which a pilot could follow and use in making an approach. The resultant configuration in an early form is shown in Fig. 8. The loop

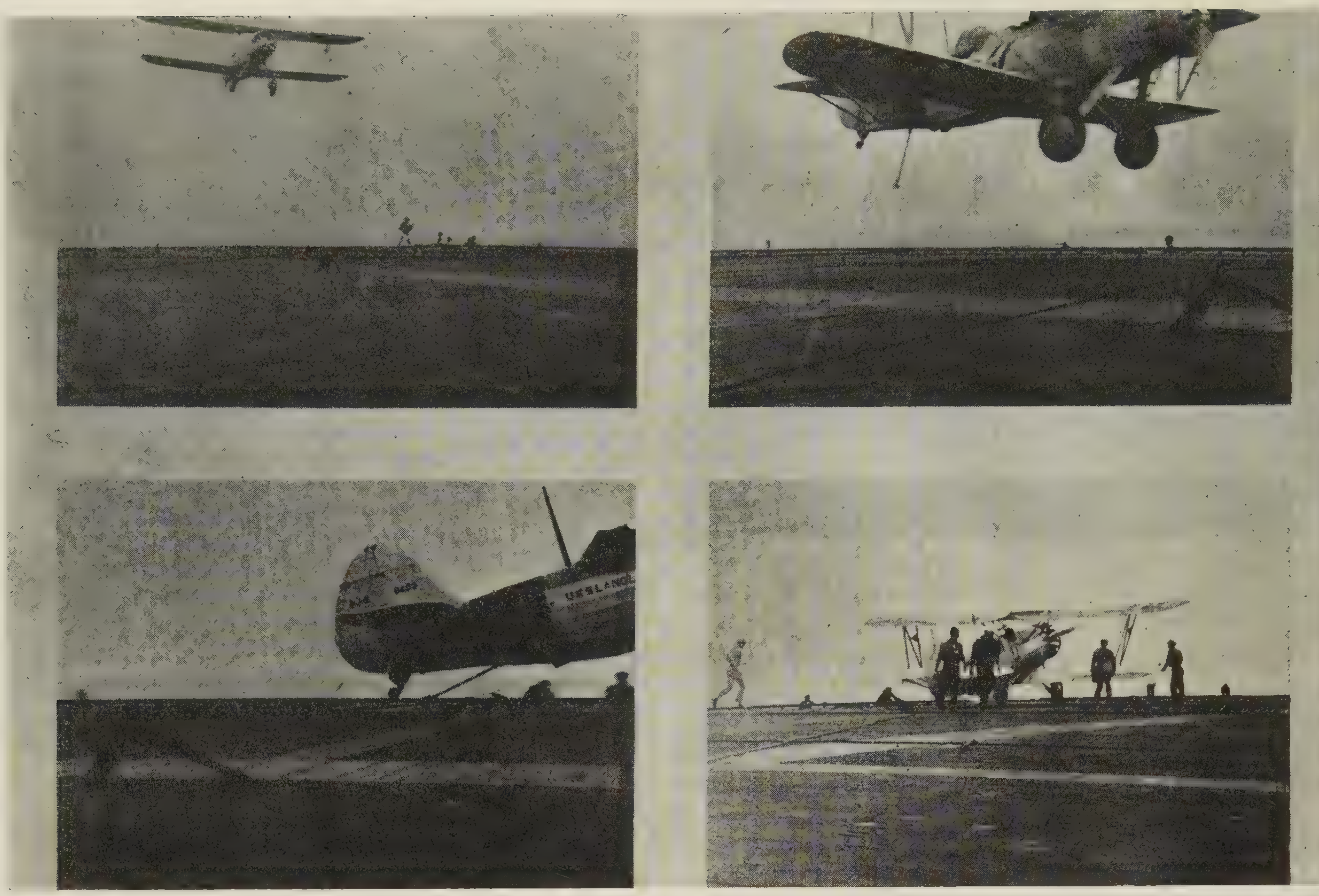


Fig. 9—OJ-2 Airplane making hooded landing on *USS Langley,* July 30, 1935.

elements were single turn as shown in the figure and produced the conventional crossed figure-of-eight pattern. While horizontally polarized radiation effects were present, they were not of sufficient magnitude to create undesirable attitude effects. Voice transmission to the aircraft was accomplished on the same channel as the localizer employing the single vertical wire located at the intersection of the loops and visible in Fig. 8.

The marker beacon presented no great problem merely requiring adjustment of the power output so that the signal was heard at the proper time and was of the proper magnitude.

Communication with the aircraft was first made from the forward radio compartment. When the elements of the system finally began to work into a coordinated whole, it was decided to turn the communications control over to the landing signal officer. His station was equipped with a head set and chest microphone which he wore while carrying out his usual signaling function. A foot operated push button was provided to energize the transmitter so that the signal officer could talk to the plane making the approach with a minimum of inconvenience.

Blind Landings at Sea

After these modifications of the equipment, a satisfactory installation was completed, one which produced reliable indications to the airplane day after day without the necessity for continued adjustments. The final efforts of two years of intensive work were had in a test flight which took place July 30, 1935 and was carried out in the following manner.

The day before, the *Langley* had proceeded to sea and the only information which was given to Lt. Akers and the aircraft detail which remained at the Naval Air Station at San Diego, Calif., was that the *Langley* would be within a 150-mile radius of San Diego. On the morning of July 30, Lt. Akers took off under the hood from the Naval Air Station, San Diego, located the *Langley* at sea and landed aboard under the hood for the first instrument landing aboard a carrier. Fig. 9 is a photographic record of the occasion from the "cut" signal to the opening of the pilot's hood.

Subsequently, numerous landings were made and it was established that with proper training and a reasonable skill on the part of the pilot, instrument landings at sea were possible. Unfortunately, test flights and training required a large amount of operating time of the *Langley.* This interfered with her duties as a fleet carrier and the instrument landing installation was never used operationally. When the *Langley* was converted into an aircraft tender shortly before World War II, the equipment was removed and stored. The Navy, however, did not lose its interest in this problem and equipment similar in type was installed in patrol plane squadrons beginning shortly

after the *Langley* tests. This later equipment was in use at the start of World War II. During the war, the Army Air Force development along these lines was combined with that of the Navy and the Civil Aeronautics Administration resulting in the present ILS system.

A project of the type described in the present paper requires the coordinated efforts of a large number of people and the cooperative assistance of many more. It would be impossible to list the names and extent of participation of all of those who are associated with it. The authors believe, however, that the following summary of some of the people and organizations involved will add substance to the story.

The story begins with the Bureau of Aeronautics, United States Navy, in June, 1933, when Rear Admiral Ernest J. King, as Chief of the Bureau, negotiated the contract which initiated the work. Later in life he was to become Fleet Admiral Ernest J. King, Commander in Chief, U. S. Fleet and Chief of Naval Operations in World War II. The contract was negotiated with the Washington Institute of Technology which was organized in 1933, for the primary purpose of carrying on this work. The president and organizer of the Washington Institute of Technology was Sidney F. Mashbir (later Colonel S. F. Mashbir, U. S. Army in World War II). The interest and enthusiasm which Admiral King and Colonel Mashbir dedicated to this project were in a large part responsible for its success.

Lt. Frank Akers, now Rear Admiral Akers and Chief of Naval Air Technical Training, came to the project fresh from the Graduate School in Radio at Harvard. An expert pilot and a competent radio man, he provided the needed skill to develop the flight techniques which were required to utilize the radio signals provided by the system and to effect a carrier landing under conditions of zero outside visibility. The safety pilot, D. L. Gentry, Chief Aircraft Pilot USN, in addition to being an expert pilot, possessed temperament which permitted him to fly day after day in an aircraft which was piloted by a man who had no outside visibility and under instructions not to touch the controls except in dire emergency. His restraint in this respect was remarkable.

The two project engineers of the Washington Institute of Technology who followed the job from the land locked airport at College Park to the expanse of the Pacific Ocean were Gomer L. Davies and Frank G. Kear. Davies and Kear had been members of the group at the Bureau of Standards which developed and tested the instrument landing system at Newark. Their work at W.I.T. was an extension of their previous research; many of their associates, engineers, and mechanics in the project were formerly on the Bureau of Standards' staff.

Credit should also be given to the Westinghouse Electric and Manufacturing Company, who cooperated with the Navy and with the Washington Institute of Technology in facilitating the supply of the basic elements from which the completed system was assembled. In particular, their development of the mechanical modulator for the range beacon or localizer and their improvements in the cross pointer instrument contributed greatly to the success of the project.

Space Exploration—The New Challenge to the Electronics Industry*

HENRY E. PREW†

Summary—**The electronics industry today faces its greatest challenge, the development of a system to control remotely a space-research vehicle. It must prepare man's path into space.**

A two-way radio data link will be one specific goal. This link should transfer data between Earth and vehicle to provide guidance and observation data, and to permit control of vehicle trajectory and instrumentation through an Earth-to-vehicle control loop. The system should operate out to Mars, a distance of 50 million miles, under extremes of temperature and radiation far above present standards, and with self-contained power sources.

A radar-beacon data link providing guidance through a simple inertial autopilot would appear to be a reasonable approach, based upon extensions to presently-developed techniques. Operating with Earth-based, 500-mc radars resembling present trans-horizon communications equipment, a vehicle beacon of 2-kw output power would permit vehicle orbiting of the Moon; 6 megw would be required to reach Mars. The respective Earth transmitters would require 200-kw and 600-megw power output.

Present remote-control equipment will not meet all the above needs; significant advances must be made before man can venture with confidence into space.

* Manuscript received by the PGMIL, August 10, 1957. Presented at the Third Annual Meeting of the American Astronautical Society, New York, N.Y., December 6, 1956. Published in *J. Amer. Astronaut. Soc.*, Spring, 1957.

† Aeronautical Equipment Div., Sperry Gyroscope Co., Sperry Rand Corp., Great Neck, N.Y.

Introduction

WITH the launching of the satellites for the International Geophysical Year, the exploration of space will begin in earnest. There is great speculation concerning the next big step beyond this endeavor. Proposals for manned space stations and reconnaissance expeditions to the moon are among the strongest proposals. Today, I wish to suggest that our present knowledge of the characteristics of space and the factors necessary to permit reasonable navigation between the Earth and even the Moon, preclude man venturing personally far into space in the next 15 years. An additional phase of exploration and experimentation seems required before means of giving reasonable assurance of man's survival in space exploration can be realized.

I submit that the use of unmanned, remotely commanded space-research vehicles, capable of providing remote observation, be used for this intermediate phase of exploration. The development of the vehicle instrumentation and the Earth-based control facilities to make this possible appears to me the great new challenge to the electronics industry.

To my knowledge, the suggestion of such a vehicle has not been made yet, and I should like to examine the general problem and discuss an approach to solving it, based upon a closed control loop concept using radio data links.

Concept of the Research Vehicle

The space-research vehicle, at first, is envisioned to be a rocket capable of higher performance than the present high-altitude sounding rockets and carrying somewhat more instrumentation. Its ability to penetrate into space would be expected to increase until it is capable of not only orbiting the Earth, but of exceeding the 7-mile per second escape velocity and making a reconnaissance of our initial goal, the Moon. The orientation and shape of the orbits of the celestial bodies which may be considered suitable for exploration during the next 50 to 100 years, are shown in Fig. 1. It seems desirable to begin now to think not only in terms of telemetering measurements to the Earth (presently being done on a limited scale with research rockets), but also to consider means for providing orbit control. Thus, the actual dynamics of space navigation can be investigated and satisfactory methods of control worked out experimentally.

One method of accomplishing these requirements, which is an extrapolation of presently used techniques, is to establish a closed command-data control loop using radio links. The vehicle's trajectory and the operation of its instrumentation then becomes the controlled output of a tremendous control loop with input-output continuity being established with radio links. The links must be capable of spanning the separations between the vehicle and a net of Earth-based control stations with a two-way flow of data. It would be expected that these control stations initially would use human operators as basic control computers. As experience and information was gained with vehicle navigation, the control and guidance operations would become, more and more, the province of an electronic computer.

Measurements of the vehicle environment with suitable pressure, temperature, and radiation sensors, and the direct observation of space and its contents with telephoto lens-equipped tv cameras, would be the type of information initially instrumented. Remotely-controlled observation with such instrumentation should provide quickly a fund of valuable first-hand information with which to extend vehicle range and control capabilities. Once the Moon has been orbited with regularity and the measurement of its characteristics has begun, then it would be time to consider seriously man's personal exploration of the Moon and the construction of space stations.

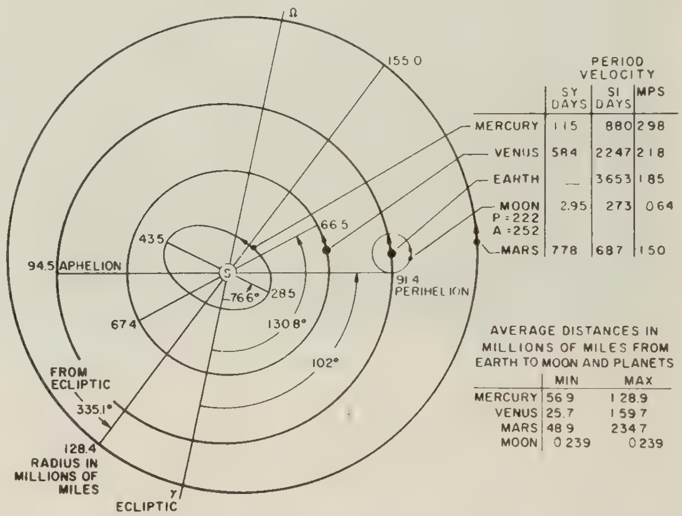


Fig. 1—Relative plane geometry of planet orbits and periods.

The nearest planets, Venus and Mars, would become the next objectives for the research vehicle. The Earth's influence on the trajectory of the vehicle would be less than in reaching the Moon, as would be the reradiated solar energy for the Earth. Essentially new problems in space dynamics and the effects of space environment would have to be faced again. Upon solution, exploratory trips to Venus, Mars, and finally, Mercury, would be possible. Because of the lower escape velocity, launchings from either the Moon or suitably located space stations would appear to be the way to begin these explorations. Now that we have talked our way to some 50 million miles from the Earth, let us go back to the beginning and consider in more detail some of the electronic problems that must be faced now. The performance required of a control-data loop will be estimated and the equipment suitable for realizing this performance discussed.

The Command-Data Loop

The radio-link control system must transfer command-data between Earth and a space vehicle. Its objective is

to provide the human operator stationed on the Earth with measurements and observations made at the vehicle. This approach avoids the much greater problems of providing instrumentation, payload capacity, and environmental controls necessary to place and sustain human life in space. It would permit, without great cost or personal risk, determination of many of the unknowns of space dynamics and environment required to develop manned space vehicles for space travel. Both operation and survival of equipment and personnel must be assured before the use of manned vehicles can be attempted.

A simplified block diagram of the radar interrogator-beacon equipment required for such a loop is shown in Fig. 2. It is seen that the command link begins with a command generator. Commands are transformed by a coder, transmitter, and antenna into high-frequency energy which radiates out into space to a complementary antenna, receiver, and decoder equipment at the vehicle. The processed signals are voltages representative of the commands. Some are fed to a trajectory system in the vehicle. This system, functionally similar to present autopilot and control surface positioning equipment but of an inertial and rocket-positioning type, determines and maintains the trajectory and the orientation of the vehicle. Other signals act to adjust and calibrate vehicle-measuring and observation equipment. It is envisioned that auxiliary-control rockets would be used to permit orientation and path control.

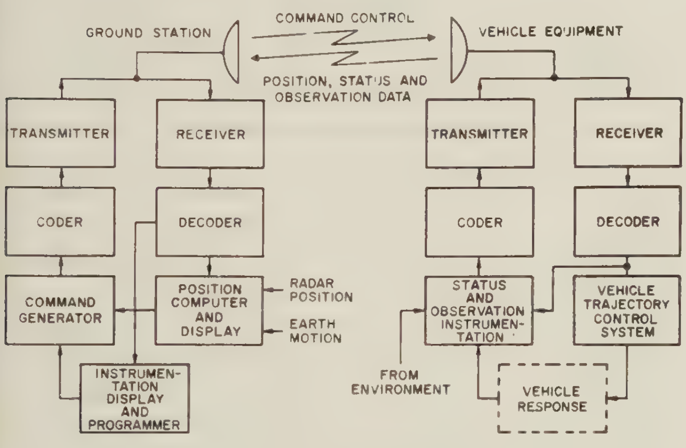


Fig. 2—Block diagram of command-data control loop.

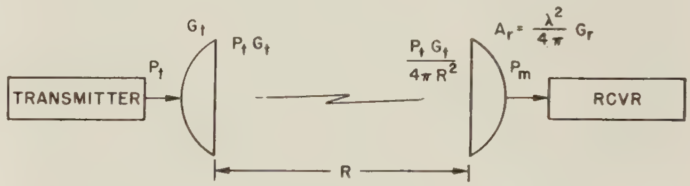
In order to generate these vehicle control commands in the ground computer, it is necessary to know continuously the vehicle's position and orientation together with the respective rates and accelerations. The position data would be expected to be derived at the Earth control stations. Angle and range data from multiple, high-power radar equipments would be fed to a master coordinate computer. This computer would establish command signals. Besides the radar's geographical coordinates and the vehicle range and angle data, the rotational and orbital position of the Earth vs a very accurate time standard will be required to eliminate Earth orientation effects on these measurements. Storage of this type of data from available tables ready for use in computers will be necessary, of course.

Data on vehicle orientation would be sent back to Earth stations over the return data link operating in much the same manner as the command link. Instrumentation status, measurements, and observation would also be returned over the data link. The returning data would be transmitted only when triggered by a signal from the Earth. This arrangement would afford a means for controlling vehicle transmission as desired, preventing indiscriminant vehicle response to signals in space and permitting range measurements to be made from the radar signals.

Radio-Link Performance and Parameters

Having established our operational and functional objectives, consider the effects of these requirements on the radio-equipment parameters and the performance needed to realize these goals.

The performance of a radio link, that is, an arrangement capable of generating rf signals, radiating them to a distant receiving equipment, and providing for detection, is characterized by the range equation. Fig. 3 shows a simple derivation of this equation. The transmitter power P_t, the associated antenna gain G_t, the receiving antenna gain G_r, and the minimum usable signal P_m of the signal detection equipment, are the equipment design factors to be considered. The range performance is also a function of frequency. Let us look more closely at these parameters as they relate to data link design.



$$P_m = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 R^2} \text{, WHICH MAY BE WRITTEN AS.}$$

$$\boxed{R_{MILES} = \left(1.48 \times 10^{-2}/f_{mc}\right) \left(\frac{P_t G_t G_r}{P_m}\right)^{1/2} \text{ MILES}}$$

WHERE P_m = KT x B x N.F. x S/N

KT = 4.1×10^{-21}, B = BANDWIDTH OF RECEIVER IN CPS

KTB = EFFECTIVE NOISE POWER GENERATED IN ANTENNA RESISTANCE

N.F = POWER RATIO OF NOISE GENERATED BY RECEIVER TO THAT GENERATED BY ANTENNA

S/N = POWER RATIO OF SIGNAL TO NOISE REQUIRED FOR A GIVEN PROBABILITY OF UTILIZATION

Fig. 3—The one-way range equation.

Frequency is perhaps one factor for which the limits of operation can be immediately restricted. Since we wish to work outside of the ionosphere, and from horizon-to-horizon in most all kinds of weather, it becomes apparent that the 100- to 3000-mc region is the most suitable of possible operating frequencies. Below 100 mc, a significant amount

of radiation will be prevented from passing through the ionosphere. Above 3000 mc, attenuation by atmospheric gases and the various forms of water vapor have significant absorption and scattering coefficients for electromagnetic radiation and preclude their further consideration.

Also, it is observed that range is inversely proportional to frequency for constant antenna gain product, G_tG_r, the physical size of the antennas decreasing with frequency. For constant-size antennas, however, the realizable range is directly proportional to frequency. The physical requirement that variations in the antenna surface shape be within 1/30 of the operating wavelength offsets this apparent advantage of increasing the operating frequency. Generally, surface variation of 0.1 per cent of the diameter is a reasonable figure to deal with physically, thereby limiting antenna gains to about 10,000.

Receiver sensitivity, P_m, is a factor which is the result of several design characteristics of the receiver. It is the signal-power level required at the receiver to obtain a signal of sufficient level above the antenna receiver and other generated noise present in the receiver output. This level is defined as that required to produce a usable display or to operate a control system with some definite degree of reliability. The signal-to-noise power ratio (snr) required to produce the desired result may vary from as much as 30 to 1 to as little as 1 to 100, depending on the type of information-coding or modulation. Rather sophisticated time-gating and integrating techniques are required to reach below a 5 to 1 ratio with high-detection probability. Pulse-coding has inherent advantages in making use of these signal detection techniques which the use of modulated continuous-wave radiation does not readily permit. It should be mentioned here that the requirement for the rate of transfer of data over a radio link is related directly to this problem of selecting the type of modulation to be used. Integration techniques in general, or any decoding method for which more than a single sample of signal is required for a single answer, will slow the effective utilization of information being sent and reduce the time response of the over-all system. A reasonable compromise between signal detection reliability and data transfer rate must always be made.

The amount of power that must be transmitted is dependent upon the several factors just discussed and the operating range desired. The ease and efficiency with which a given amount of power can be generated is highly dependent upon the operating frequency. The techniques and the components available in the 100- to 3000-mc band change from conventional lumped constant type circuitry to continuous-waveguide structures; in general, the lower the frequency, the less complex the equipment. The use of pulse modulation permits large amounts of peak power to be generated with a relatively small amount of driving power. Peak powers in excess of 1000 times that possible on a continuous wave (cw) basis can be realized.

This discussion of the range equation and its parameters has been for the purpose of clarifying the bases upon which Fig. 4 was developed. The curves of this figure show the transmitter powers which will be necessary at 500 mc to reach out into space for establishing command-data links. Both the antenna-gain product, G_tG_r and receiver sensitivity, P_m are parameters. It should be emphasized that balanced data links are required; that is, the range capability from Earth-to-vehicle should be equal to that from vehicle-to-Earth. This does not mean, however, that the values of the parameters in the range equation have to be the same for each link. In fact, it is highly desirable to arrange for the highest transmitter power, largest antennas, and the most sensitive receiving equipment to be placed on the Earth where space, power, and environmental conditions are satisfied most easily. The vehicle equipment would be designed then, to require a minimum of space and facilities.

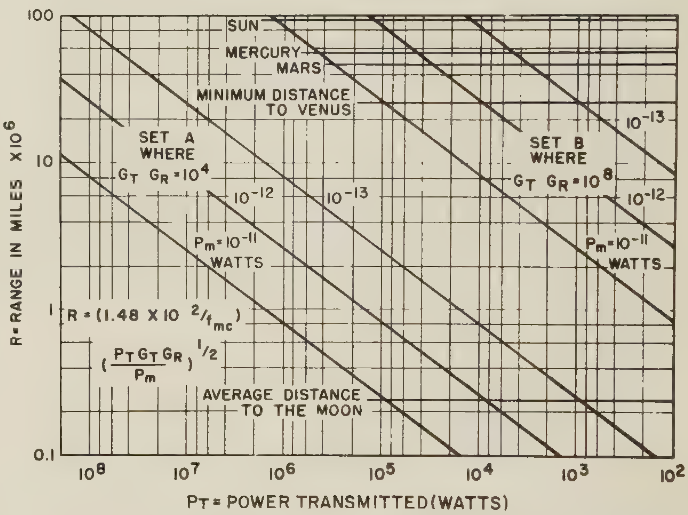


Fig. 4—Range of operation R vs transmitted power P_T at 500 mc.

Returning to Fig. 4, and looking at curves of set A we see that about 200 megw of power is necessary at 500 mc to reach 100 million miles, when using a receiver of high sensitivity (10^{-13} watts), with a highly directional 2° tracking antenna of 10,000 gain on the Earth and a simple omnidirectional dipole antenna on the vehicle. To reach the Moon, under these circumstances, requires only about 1000 watts; a much more reasonable figure. However, if we consider the possibility of using an antenna on the vehicle comparable to the ground unit, we can reduce our transmitter power needs by a factor of 10^4. This reduces from 200 megw to 20 kw the transmitter power needed for planetary operation and from 1 kw to 0.1 watt, the power for lunar operation, as indicated in the B set of curves. The role of the antenna, in reducing power requirements is seen to be very important. However, an antenna of 80 feet in diameter is required at 500 mc to realize 10,000 gain. At 3000 mc, only a 15-foot antenna is required, but the transmitter power must be 36 times greater than at 500 mc for the same range performance.

A realistic look at these results is quite sobering. Even a range of 100 million miles, a fantastic figure compared with present radio-data link equipment performance, is not really enough performance to cover completely the orbits of any of the planets we have been considering. A range approaching 200 million miles is required to reach Mars when it is moving towards the opposite side of the Sun from the Earth. If the tracking and acquisition problems inherent in the use of a narrow-beam antenna on the vehicle is solvable, all is well; otherwise, we are limited to ranges of a few million miles. It is then that space stations and signal-repeater satellites will come into their own as necessities for navigation and communication. In any event, the exploration of space between the Earth and the Moon must come first.

A Command-Data Loop for Lunar Exploration

Now we can begin to suggest definite equipment configurations for the control loop for a space-research vehicle suitable for lunar exploration.

Let us observe the situation of Fig. 5(a) showing the Earth-Moon geometry. First, we can take 300,000 miles as a conservative range requirement. If we select our operating frequency as 1000 mc, a compromise among physically large antennas, atmospheric losses, and transmitting equipment efficiency, the transmitter power required by the radio links is four times that at 500 mc. This corresponds to about 5 kw for operation with a 30-foot parabolic control station antenna, a dipole-vehicle antenna and a receiver sensitivity of 10^{-13} watts. It seems desirable now to redistribute the above basic transmitter power and receiver sensitivity values so that the vehicle equipment is as simple, compact, and low in operating power as possible. We transfer thereby, complexity and power requirements to the Earth-based stations. The resulting specifications are shown in Fig. 5. The Earth-based control station requires a 500-kw transmitter and a receiver capable of operating with a signal power of $4 \cdot 10^{-14}$ watts, while the vehicle beacon values would be 2 kw and 10^{-11} watts, respectively.

We would expect the Earth-based control stations to be permanently located, high-powered, tracking radar units, using pulsed coding for both range determination and data and command coding. They would operate with a 30-foot parabolic antenna with a beam width of about 2° and have a high-performance receiver. Also, they would consist of the computer equipment necessary to determine from both radar and Earth motion data, the trajectory of the vehicle, and by comparison with precomputed orbits determine the corrective control action required. It seems possible that three, or at the most four, such stations arranged about the Earth within 30° of the equator, could maintain continuous control of the vehicle as the Earth rotates. Control switchover between stations should not be difficult since passive tracking on the vehicle beacon return-data signal by an acquiring station, would be possible before actual command control was transferred. Even a single station might be usable initially since the vehicle's free-fall orbit could be estimated and its position anticipated on each rotation of the Earth. In addition, excursions with the vehicle could be made when the Moon was full and visible above the horizon for almost 12 hours.

The vehicle beacon would consist of a relatively low-power transmitter, a medium sensitivity receiver, and coding and decoding equipment. It would operate with a dipole type wide coverage antenna. The equipment would be expected to weigh about 50 pounds and operate with less than 500 watts of input power. A major problem would be in designing such a beacon to meet the environmental requirements of space.

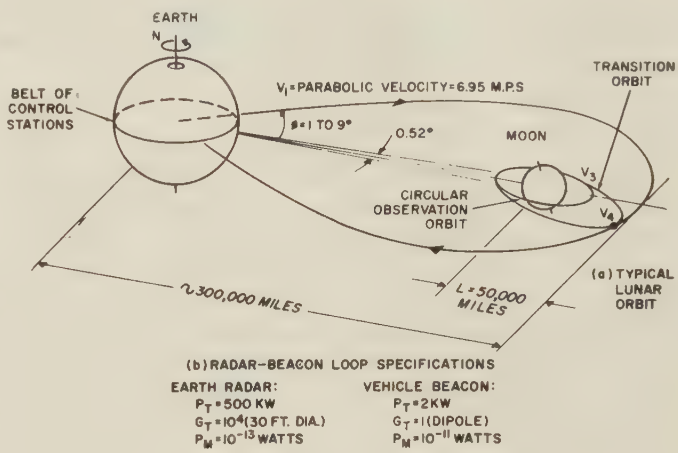


Fig. 5—Lunar orbit specifications.

Referring to Fig. 5(a) again, a typical type of orbit for experimental lunar trips is depicted. Only a single orbiting of the Moon would be expected to be attempted at first, with ascent at very close to parabolic velocity requiring a transit time of somewhat more than one day. If the launch-angle were held to within limits indicated, 1° to 9°, the vehicle would return to Earth after traveling around the Moon. It is assumed the vehicle could be slowed on command as it approached the Earth so that atmosphere re-entry could be accomplished and recovery made of the vehicle.

On subsequent trips, control rockets could be commanded to slow the vehicle at *a* sufficiently to produce an elliptical orbit tangent to a desired circular orbit. At the tangent point *b*, further adjustment of velocity would produce this circular orbit about the Moon. When it was desired to return to the Earth, command signals would be used to increase the velocity at *c* to establish a new transition ellipse tangent to the original path at point *a*. At this point, upon a final increase in velocity, the vehicle would return to the Earth along the original orbit. Curves of the velocities required to produce circular orbits about the Earth and Moon vs the distance from the terrestrial and lunar surface are presented in Fig. 6. To orbit at 200 miles from the Moon requires a tangential velocity of about 0.8 mile per second as compared with the Moon escape velocity of 1.47 miles per second and the original Earth escape velocity of 6.95 miles per second.

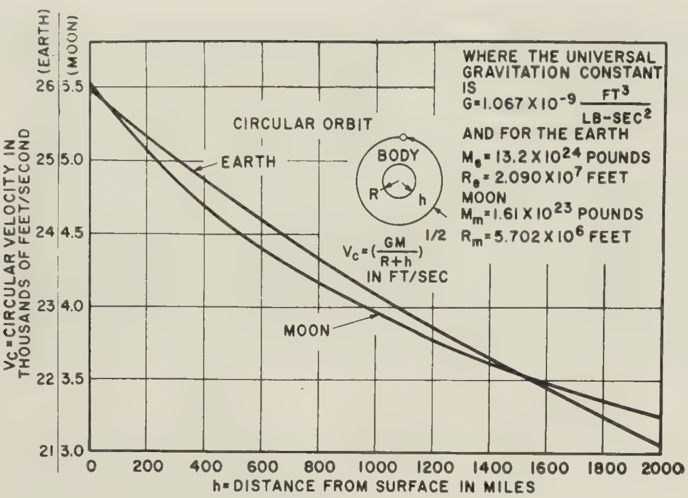


Fig. 6—Circular orbital velocity V_C vs distance from surface of Earth and Moon.

The previous discussion must be considered to be a rough indication of a mode of operation for the purpose of illustrating the utility of a command link. In reality, the trajectory would have to require the changing of vehicle velocity in three dimensions since the Moon's orbit is tilted about 5° to the Earth orbital plane and both the Moon and Earth are rotating about a point some 1060 miles below the Earth's surface. I am not prepared at this time to go beyond this rather brief description of a possible manner of using a command-data loop. In fact, although the use of auxiliary rockets for trajectory control with Earth satellites in all likelihood will be investigated, until actual experimental tests are run with remotely commanded space vehicles the feasibility of trajectory control cannot be accurately known. There are just too many variables and unknowns to predict the result analytically.

The Unsolved Problems

It appears from the foregoing, assuming the practicality of a rocket vehicle capable of escape velocities with about 500 to 1000 pounds of payload and sufficient fuel for control rockets, that the goal of a command-control research vehicle for traveling out to the Moon at least is within the present state of the electronic art. There is one large area which is a real immediate challenge to the electronic industry. How do we build equipment to operate in the environment of space? Although we have very meager knowledge of physical conditions in space, we can estimate that problems associated with temperature, pressure, and high-energy particle radiation will be severe, at least initially.

How do we deal with conditions where solar radiation produces temperature differences on the vehicle surface so great that oxygen liquifies on the shadow side and water evaporates on the other? Perhaps the suggestion of a thermos bottle construction might be the answer, perhaps not.

What do we do with a vacuum harder than any we will probably ever realize on Earth? Do we build tubes without envelopes to make use of this characteristic? Do we hermetically seal or eliminate anything susceptible to leakage or evaporation under low pressures?

Will these conditions, coupled with meteoric dust, produce high levels of erosion, and make optical instruments unusable by clouding the lenses or transparent covers?

What are the effects of primary cosmic ray particles? Will they produce a new type of radio noise? What will be their effects on semiconductors such as transistors and diodes which would be expected to be used extensively in vehicle instrumentation?

These are some of the important areas where conclusive answers are not presently available. They pose questions whose answers will be gained only through the usual procedure of research. The environmental measuring equipment planned for the Earth satellites is a beginning and, based on the data collected, equipment to go further into space should be able to be built. We would anticipate continuing this approach, optimistic that new techniques and components will be discovered to meet each new set of requirements. With this in mind, the 15-year delay before man ventures into space seems rather short, does it not?

Conclusion

The electronics industry will soon be asked to design and build electronics for space exploration. Hyper-range guidance and data links, operating with command control loops to navigate space research vehicles, would seem to be a major portion of the initial requirements. In addition, environmental sensors, both optical and electronic, would be a second, very extensive, demand. Within the present knowledge of space dynamics, equipment to permit exploration trips to orbit the Moon would not require significant extensions in presently available electronics techniques. However, the need to operate this equipment out in space is something to be reckoned with.

The challenge has been posed, let's roll up our sleeves and go to work!

New Look at Submarines*

C. B. MOMSEN†

THE submarine of the future promises to be the most versatile and most powerful warship ever conceived by man. The appearance of this new submarine will pose tasks for all engineers in finding countermeasures and I think that it is timely to begin thinking about that now.

The submarine with its various weapons is a weapons system and, like all weapons systems, is continuously undergoing changes to meet new standards resulting from developments of new component parts. Integration of improvements into a weapons system is, as a rule, a continuing process. We add a little speed to a vehicle, improve its protection, perhaps modify controls or provide new weapons for its use. Most of the modifications take place as alterations during routine overhauls or when a replacement program is planned. Once in a while a major breakthrough occurs which calls for very radical changes and, when this happens, it tends to unbalance the status quo of the combination which makes up a war machine.

I will cite a few examples of major changes that have been the cause for radical modification of balanced war machines.

1) When the ancient Chinese discovered that saltpeter, charcoal, and sulphur properly mixed would burn quickly in confined spaces and create hot gases about 1500 times the volume of the original mixture, they had discovered gun powder. The use of gun powder caused an astounding change in the nature of warfare.
2) While there had been some crude applications of the properties of steam to power, it was not until 1769 that James Watt patented the first practical steam engine. Thirty-eight years later Robert Fulton, in 1807, put the first steam engine in a boat. This led to the conversion of warships from sail to steam.
3) The development of techniques for harnessing electric power caused many changes in warships, but a major breakthrough occurred when it became possible to use electric power from storage batteries to propel a submarine under water.
4) When the Wright Brothers demonstrated that airplanes would fly, another dimension was added to warfare and another major breakthrough began.
5) The application of radio to communications and warfare came shortly after the turn of the century, and this must be considered as a major breakthrough because of its effect upon the mobility and strategy of armed forces.
6) When radar was introduced to warfare in World War II, man was able to "see" things not discernible to the eye. This had an important effect upon tactics, and must be placed in the front ranks of the list of major breakthroughs.
7) Toward the end of World War II, the U. S. dropped an A-bomb on Hiroshima. While it might be said that this was just another explosion, the magnitude of a nuclear explosion is so enormous that its effect on warfare was far reaching. Then when the reaction was controlled in such a way that the heat could be used for a power plant, it paved the way for one of the greatest breakthroughs of all.

It is difficult to place missiles into a time scale relative to nuclear energy because their development has come along during about the same period. However, the great ranges attainable by guided missiles and their tremendous destructive power place them in the category of a major breakthrough in warfare. The major breakthroughs which I have mentioned, date about as follows:

Gun powder	1000
Steam power	1807
Electric power	1900
Aircraft	1903
Radio	1915
Radar	1940
Atomic energy	1944
Guided missiles	1950.

What can we expect in the future? These important changes seem to be coming with greater frequency. For instance, six of the eight have taken place in the past 57 years. Certainly we cannot be so naive as to think that this rate will suddenly stop. If the rate of change continues in the next 50 years, and I believe that it will, it is difficult to visualize what it is leading to. We have now the capability to travel through the air at considerably more than 10 miles a minute, to strike targets thousands of miles away with unimaginable destructive force. There is no place left to hide except underground or under the sea.

I class the coming high-speed submarine as the next important breakthrough in naval warfare.

In a recent speech, Secretary of the Navy Thomas S. Gates, Jr. said, in part, "The Nautilus which, when com-

* Manuscript received by the PGMIL, June 10, 1957.
† Vice Admiral, USN (Retired), 719 N. Overlook Drive, Alexandria, Va.

bined with an advanced Albacore hull and armed with guided or ballistic missiles with speed, strength, endurance, and maneuverability, will give us a weapon system which approaches the ultimate as a weapon of deterrence or retaliation." "Ultimate" is a strong word, but indeed this new weapon system will be worthy of such a description. The submarine of the future will become a submersible which only occasionally comes to the surface, in contrast to present conventional submarines that are basically surface ships which occasionally dive below the surface. The breakthrough is made possible of course, by the successful development of a nuclear power plant. Nuclear power, in contrast with conventional power plants now in use, does not require oxygen for power generation. Therefore, it provides plenty of power to propel the submarine underwater for long periods of time.

With a ship on the surface one of the important deterrents to high speed is the wave-making losses. When a hull is completely submerged several diameters below the surface, wave making is almost eliminated. This, then, is the reason that the submerged submarine, once adequate power is available to it, will be able to make speeds considerably greater than surface ships. This is the the reason that the new submarine is a breakthrough comparable to gun powder, electrical power, aircraft, radio, radar, atomic weapons, and missiles.

There can be no doubt that this submarine will approach the ultimate as a seagoing system. Recently, I noted this passage in D'Arcy Wentworth Thompson's great book, "On Growth and Form": "Human comprehension, like sound waves, light, colors, etc., lives in a limited spectrum. The universe is too great for us to behold, the virus too small. Both are beyond our spectrum of comprehension." There seems to be a tendency for people to accept without challenge that human comprehension lives in a limited spectrum. Fortunately, this is not true in the area of electronics —an area that has advanced with astounding strides in the past 30 years. Yet even in this area, we find people who are inclined to believe that we have just about exhausted all of the possibilities. For instance, I listened recently to a talk by a prominent scientist who wrote a book 20 years ago in which he undertook to forecast some of the future developments in electronics. He admitted that in his book he had stated that television seemed to be a possibility, but he added that he did not believe that his eyes would ever see it.

Now, what about the future? May I be so bold as to gaze into the crystal ball and do a bit of forecasting? I am encouraged to do this because nature has, through the creation of fish, provided a fine target at which to shoot. If we could do with a submarine the things that fish can do we would have a hydrodynamic vehicle far superior to anything in existence today. During the centuries of evolution, species of fish that were too slow or too noisy were eaten by others. Only the near perfect hydrodynamic types survived. In the course of many hours under the sea in submarines, in diving bells and in diving suits, I have observed that they seem to be able to maintain precise neutral buoyancy and trim. They can start and stop with no apparent effort. There are no signs of turbulence even when they move quickly. I have seen a barracuda appear suddenly before my eyes—stop dead in the water—then disappear like a flash, yet leave no sign of disturbance in his wake. Qualified observers using hydrophones have been unable to hear fish swimming even at high speeds and making radical course changes. With these things for ammunition I feel safe in reading in my crystal ball that:

1) Submarines of the future will be capable of speeds 20 to 30 knots greater than that of surface ships.
2) Submarines will be so quiet that they will be undetectable by passive devices even though running at top speeds.
3) For all practical purposes there will be sufficient air for breathing for unlimited endurance submerged. When these characteristics are achieved it seems reasonable to foresee that the submarine can carry various types of weapons which will give it the capability to destroy surface ships, aircraft, and land targets that are many hundreds of miles from the shore. I suspect that submarine ports will be deep underground and will be entered by means of submerged tunnels well below the surface of the sea.
4) Finally, let me return to nature for guidance. I see that in the process of evolution no creature exists which lives solely on the surface of the water. It would seem that if there ever was such an animal, the birds in the air and the fish in the sea eliminated it. This then, suggests that when the new submarine is perfected, surface ships will not be able to survive the threat from aircraft and submarines. From this deduction I forecast that the seas will be controlled by aircraft high in the air above it, and submarines deep in the ocean. Likewise I forecast that overseas transport will be by means of these underwater vehicles.

In the past, we have not given a great deal of thought to the matter of maintaining precise neutral buoyancy or to exact trim in a submarine. The speed capabilities have been so puny that the submarine was regarded as a mere weapon of opportunity. That is to say, it had to be pretty much in the path of its adversary if it were to be able to get into an attacking position. Recently I have had an opportunity to observe some tests at the David Taylor Model Basin, which demonstrated quite clearly that while form of an underwater body is important, it is even more important that the axis of the body be parallel to the direction of motion in all planes. Thus, both trim and buoyancy are important for efficient underwater movement. For the same reason any pronounced asymmetry causes increased drag. Furthermore, as has been observed on surface ships, losses in speed can be avoided by care in steering and in depth control.

Now that we have an idea of what this beast will be, let us lay it open and see what the engineers must do about it.

There are four principal areas of interest; namely, controls, communications, detection, and navigation. Operating a submarine in a relatively thin layer of the ocean at very high speeds requires quick acting automatic control systems that are very accurate and foolproof. An eminent scientist, Dr. Edward Teller, once said that the only way to make something foolproof is to remove the fool. Perhaps this is so, but we must endeavor to perfect these controls system so well that they will operate safely in spite of the fool. A submarine moving at 60 knots would, if it took a down angle of 25°, change depth at the rate of 44 feet per second. Thus, if its maximum operating depth were 1200 feet and it started at 300 feet, it could be dangerously deep in 21 seconds. On the other hand, let us note that 44 feet per second is faster than the sinking rate of most objects dropped into the sea. Therefore, there would be a requirement for such a maneuver for evading certain antisubmarine weapons which are dropped. This then, suggests a need for detecting the impact of a weapon which is dropped into the sea so that evasive action can be taken.

The problems of communication are pretty well known. It is sometimes said that things that are impossible take a little longer to do. Perhaps deep penetration of electromagnetic waves into the sea is impossible, but it would be a great help if someone were to find a way of using radio and radar under water. Of course, we can receive radio communications but only at very shallow depths. It appears that sound in water will continue to be the principal means of exchanging intelligence. Because of the high attenuation of sound waves at high frequency, we are more apt to meet with success if we confine our attention to the very low frequencies. There is a requirement for long and short range communications with submarines deeply submerged.

From the standpoint of antisubmarine measures it is not too early to start thinking about countermeasures to be used against the new submarine. Antisubmarine warfare includes measures to destroy the submarines at their point of origin, detecting and destroying them at sea, mining them, and avoiding their weapons. If the new bases are deep underground, they will be very difficult to reach. If the submarines are quiet, they will not be heard by passive detectors. If active detectors are used, the submarine being forewarned can use its speed to evade an attack. Mining is limited to fairly shallow depths. Finally, as far as surface ships are concerned, it would be very difficult for them to avoid weapons if the submarine had a large speed advantage and used it to obtain a favorable firing position.

The third important area of interest is detection. It is indicated that the deeply-submerged submarine will have to depend upon sound for detection of its adversary. It is safe to say that the submarine will always have the advantage over surface craft insofar as sound detection is concerned. There is, however, considerable doubt that the sound emitted by aircraft will be detectable at useful ranges by the submarine. As far as other submarines are concerned the advantage will lie with the one which, by construction or by operational commitments, is most quiet.

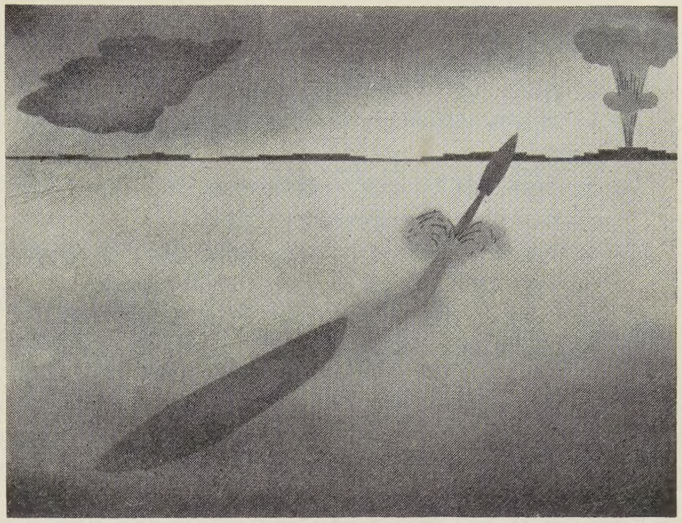


Fig. 1.

In any event, we will need much improved sound equipment. Perhaps we should say that we should lay the sound gear rather than the keel when we build a new submarine.

The fourth important area of interest lies in methods of navigation. With land always within five miles of the submarine—usually straight down—there seems to be no reason not to use fixed positions on the sea bottom for navigation. Perhaps inertial principles will provide a better answer for navigating.

While I have mentioned these four areas as the principal ones, there are some others that are quite important. For instance, as greater submerged endurance is achieved for machinery, the problem of providing clean breathable air for personnel becomes acute. Man uses oxygen and generates carbon dioxide. It is not too difficult to carry large quantities of oxygen by compressing it to high pressures and storing it in steel flasks. Carbon dioxide removal, however, is not so easy. Chemicals do a fair job of absorbing it, but do not clear it out entirely. In addition to this it takes large quantities of the chemicals. Scrubbers are fairly effective, but certainly not ideal. There have been some chemicals developed which wiil absorb CO_2 and give off oxygen. There is also some carbon monoxide present and this adds to the air purification task. A solution would be to require all personnel to breathe through an efficient gas mask, but I do not believe they would take kindly to this. Of course, reduction of the number of personnel required to operate the submarine by developing a high state of automatic controls would help a lot.

In concluding let me review the salient features of the Future Submarine as I see it.

1) It will have high speed—sixty knots or more.
2) It will have great submerged endurance.
3) It will operate silently.
4) It will have a high degree of automation, and consequently, smaller crews.
5) It will have accurate underwater navigation capabilities.

6) It will have "big ears;" that is, very effective listening equipment.
7) It will be highly maneuverable.
8) It will be somewhat smaller than the present submarines.
9) Its ports will be deep underground and they will be entered through underwater tunnels.
10) It will carry guided missiles, both water to air and water to land (Fig. 1, p. 51), and tropedoes.

I believe that all of these features are attainable and that when they have been incorporated in the new submarine we will certainly come close to what the Secretary of the Navy describes as the ultimate weapons system. Now is the time for our engineers and scientists to contemplate this new weapons system and to search for new methods to counteract it. Seapower will always be important to us, and whether we use the surface of the sea, or the air above it and the depths below it, to control the seas does not matter much—so long as we are able to continue to hold the vast sea areas as barriers to protect our homeland and to project our might to those countries threatening our own.

Contributors

F. Akers

Frank Akers was born in Nashville, Tenn., March 28, 1901. After secondary schooling at Wallace Univ., he entered the Naval Academy at Annapolis and graduated with a Bachelor of Science degree in 1922. He served on the destroyers of our Pacific Fleet until he was assigned to flight training at Pensacola and was designated a naval aviator in 1925. He again returned to the fleet where he was in various fighting squadrons until ordered back in 1928, as an instructor in the Flight Training School at Pensacola.

He took post-graduate work at the Naval Academy and later at Harvard Graduate School where he received the M.S. degree in electrical communications in 1933.

He engaged in two years' intensive instrument-landing development work for the Bureau of Aeronautics both ashore and at sea. He progressed through the officers grades of the Navy and at the outbreak of World War II, was Navigator of the *USS Hornet* during the Doolittle Raid on Tokyo and the Battle of Midway. Later in the war, he commanded the aircraft carrier, *USS Saratoga*. He had two tours of duty as Director of Electronics in the Bureau of Aeronautics. He was promoted to Rear Admiral in May, 1949, and since that time, has commanded aircraft carrier divisions in the Pacific, Atlantic, and Mediterranean. His present assignment is Chief of Naval Air Technical Training with headquarters at the Naval Air Station, Memphis, Tenn.

❖

F. G. Kear

Frank G. Kear (A'24–M'31–SM'43–F'53) was born in Minersville, Pa., on October 18, 1903. He received the E.E. degree (cum laude) from Lehigh University in 1926, the S.M. degree in 1928 and the Sc.D. degree in 1933, both in electrical engineering from the Massachusetts Institute of Technology.

Dr. Kear was associated with Dr. V. Bush, in 1926–1928, in the development of the product integraph and the differential analyzer. From 1928 to 1933, he was engaged as a physicist in the Aeronautical Radio Group at the National Bureau of Standards. For the next eight years, he was Chief Engineer of the Washington Institute of Technology, in charge of development of radio aids to air navigation. Since 1941, he has been a senior partner in the consulting engineering firm of Kear and Kennedy. During World War II, 1941–1945, he was Head of the Radio Section, Electronics Division, Bureau of Aeronautics, United States Navy.

Dr. Kear is a member of the Society of Motion Picture and Television Engineers, the Association of Federal Communications Consulting Engineers, Eta Kappa Nu, Tau Beta Pi, Phi Beta Kappa, and Sigma Xi.

❖

C. B. Momsen

Charles B. Momsen was born June 21, 1896, in Flushing, N.Y. He was graduated from the U.S. Naval Academy with the B.S. degree.

He volunteered for submarine duty in 1921 and, together with several colleagues, invented an individual escape device known as the "Momsen lung." He also assisted in the design of towers at New London and Pearl Harbor for training men to escape from submarines. He was later made Officer in Charge of the Experimental Diving Unit in Washington to investigate the use of helium and oxygen for deep sea diving.

In 1943, Admiral Momsen returned to submarine duty and took part in the investigation of the failure of torpedoes to explode when striking the target. In 1951, he was ordered to command the Submarine Force of the U.S. Pacific Fleets and in 1954, was chosen Commander of Joint Task Force Seven in charge of nuclear weapons tests in the Pacific. Upon his retirement in 1955, he was promoted to Vice-Admiral.

He is now a consultant to General Dynamics Corp., U.S. Rubber Company, Raytheon Manufacturing Corp., and the Coleman Engineering Company.

❖

H. E. Prew

Henry E. Prew (M'56) was born on May 10, 1925, in Springfield, Mass. He received the B.S. degree in physics from Yale University in 1950.

He is systems engineer for radar guidance and control in the Aeronautical Equipment Division of the Sperry Gyroscope Company, Division of Sperry Rand Corporation, Great Neck, N.Y.

Mr. Prew was engaged in research and development for electronic compass systems, counter measures, and uhf and microwave receivers and transmitters prior to his joining the Sperry Gyroscope Company. His scope of activities have encompassed system planning, analysis, and feasibility development for drone and missile guidance systems. He holds a patent resulting from his uhf work.

Mr. Prew is a member of the American Astronomical Society.

INFORMATION FOR AUTHORS

The PGMIL Transactions is intended to bridge the gap between the various disciplines contributing to military electronics. Since this includes most of the branches of electronics, the military, and many fields which are associated with but not actually within the realm of electronics, it is essential that the papers published be of broad interest. The emphasis should be on readable, thought-provoking material that stimulates an attitude of open mindedness and curiosity.

Papers are solicited in the following general subject categories:

Military sciences—Military science fiction, famous battles involving electronics, basic problem areas of military electronics.

Technical survey—Tutorial technical papers on radar, communications, navigation, systems and operations research, etc.

Integrating papers—Integration of concepts common to several fields, as for example, wave phenomena, information theory, etc.

Physical sciences—Fundamentals of modern physics that may influence the future of military electronics.

Mathematical concepts—Applications and implications of modern mathematical methods.

Associated subjects—Survey of fields that are neither military nor electronic but which are important to the advancement of military electronics.

Manufacturing—Industrial and military problems of reliability, quality control, etc.

It is requested that each paper be submitted in duplicate. Standard IRE practice should be followed in preparation of the manuscript and illustrations. Papers should be sent to James Q. Brantley, Jr., or Donald R. Rhodes, PGMIL Editors, P.O. Box 6904, Orlando, Fla.

INVITATION TO MEMBERSHIP IN PGMIL

Members of the IRE may join the Professional Group on Military Electronics as active, voting members by payment of the annual fee of \$2.00. Nonmembers of the IRE who qualify may become nonvoting affiliates under the new IRE affiliate Plan by payment of an annual fee of \$4.50 in addition to the assessment of the Group. All applications for membership affiliation should be addressed to the Chairman of the PGMIL Membership Committee, William M. Richardson, The Ramo-Wooldridge Corporation, 1300 Connecticut Ave., Washington 6, D.C., or to IRE Headquarters.

INSTITUTIONAL LISTINGS

The IRE Professional Group on Military Electronics is grateful for the assistance given by the firms listed below, and invites application for Institutional Listings from other firms interested in the field of Military Electronics.

The charge for an Institutional Listing is $75.00 per issue or $225.00 for four consecutive issues. Applications for Institutional Listings and checks (made out to the Institute of Radio Engineers) should be sent to Mr. L. G. Cumming, Technical Secretary, Institute of Radio Engineers, 1 East 79th Street, New York 21, N. Y.